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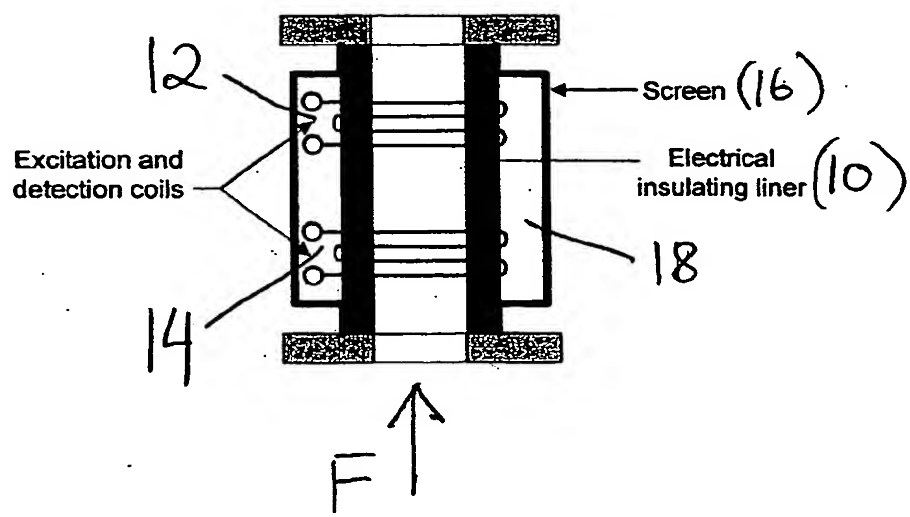
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND ARRANGEMENT FOR MEASURING CONDUCTIVE COMPONENT CONTENT OF A MULIPHASE FLUID FLOW AND USES THEREOF



(57) Abstract: The present invention relates to a method and an arrangement of measuring conductive component content of a multiphase fluid flow and uses thereof. The claimed device comprises two coils arranged around the pipe containing the fluid to be measured, where the induced power loss in the mixture is determined, thereby determining the content of the conductive component. Alternatively, a number of coils are arranged on the outside surface of the fluid transporting pipe and the power loss or attenuation of magnetic field is determined.

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METHOD AND ARRANGEMENT FOR MEASURING CONDUCTIVE COMPONENT CONTENT OF A MULIPHASE FLUID FLOW AND USES THEROF.

The present invention relates to a method and arrangement for measuring conductive component content of a muliphase fluid flow. Applications of the method and arrangemet are also disclosed.

In particular the method and arrangement are well suitable for determining a water content in flows, in particular in mixtures of oil, HC-gases and water, in a fluid transporting body.

The water fraction meters used in the oil process industry to day will all be influenced by the gas content in the oil/water/gas-mixture and different kind of iterative algorithms are used to compensate for this error. Micro wave meters are dependent on the salinity of the water component in both oil and water continuous phases and capacitance meters must be equipped with a conductivity meter to cover the whole range of water fraction from 0 to 100%.

The object of the present invention is to provide for a method and arrangement to be able to effect determining

the content of a conductive fraction in a multiphase flow wherein the conductive phase exist in a range of being continous or being included in the muliphase flow as droplets.

A multi phase flow of water/oil/gas may exhibit a water-continous phase or an oil-continous phase, for example.

In particular the purpose of the invention is to provide for a method and apparatus to determine the conductive water phase in said whole range of water-continous and oil-continous phases.

The method according to present invention is characterized by on line measuring the fraction of the conductive component in the multi phase flow by using a coil design optimised for non-conductive continous mixtures, and a coil optimised for conductive continous mixtures mixtures.

The preferred embodiments appear in the dependent method claims.

The arrangement according to present invention appears in independent claim 14.

The preferred embodiments of the arrangement appear in the dependent claims 15-20.

According to the invention, the method and arrangement according to preceding claims, are suitable for determining the water content of a multi phase flow of oil, hydro carbon gases and water, in that water is the conductive component to be determined, and the oil and gas phases being the non-conductive phase.

According to specific embodiment, the method is used for measuring the water content in oil/gas/water multiphase mixture flows wherein the different phases in the crude are separated, i.e. not homogeneous mixed.

In the following the invention will be disclosed in relation to a multi phase mixture of water, oil and gas, while it is obvious that it may be applied to any multi phase mixture including one liquid conductive phase.

The water fraction meter described thus can detect the water fraction in tree phase flows on line independent of the gas content in the mixture. To day the conductivity of the water component is determined off line by laboratory tests of processed water. The described instrument can monitor the water conductivity on line.

The invention will be explained more in detail by referring to the enclosed drawing figures, in which:

Figure 1 shows a section of the arrangement/instrument (the meter spool principle) according to the invention.

Figure 2 shows a curve of the penetration depth as a function of the frquency of the coil, i.e. the skin depth in Tm of the Cu lead (conductor) of the coil as a function of frequency (Mhz).

Figure 3 shows the result an experiment measuring an oil/gas/water mixture phase with a particular coil design, as the impendance as a function of the water fraction in a multi phase flow to be determined. This coil design is sensitive for the water content in the mixture over the whole range, i.e. from the oil continous phase to water continous phase. The steep area of the curve represents the transition area between the oil-contious (left side of curve) and water-continous phases (right side of curve).

Figure 4 shows the results of measurements effected with a coil which has increased sensitivity for oil/gas continuous mixtures phase (the left side of curve).

Figure 5 shows the measurement results of using a coil configuration of an increased sensitivity for water continuous mixtures (right hand side of curve).

Figure 6 shows an arrangement for utilising this induction principle in a tomographic arrangement.

Figure 7 shows a a detail of a coil unit design which is connected to the pipe surface.

MEASUREMENT PRINCIPLE

A sketch of the meter spool pipe principle is shown in the enclosed figure 1. There is shown an electrical

insulated liner 10 (a coil pipe) around which exitation and detection coils 12,14 are arranged. The insulated liner may be a pipe prepared of a ceramic, plastic or a peek material and is, with all elements intsalled, arranged to be inserted in fluid flow conducting pipe. The coils 12,14 are protected by a screen (a steel material) 16 enclosing the central pipe section. The space between the screen and the pipe outer surface is filled with an inert material. The purpose of the screen to make resistance to the fluid flow pressure inside the liner 10. Each coil of number 12 and 14 is used as exitation and detection coils. The coils are parts of an oscillator unit supplying alternate voltage to the coils. The oscillator frequency is dependent of the inductance and capacitance of each coil. Each coil 12 and 14 includes different number of coil windings. The coil wires are preferaly made of flat Cu-lices (copper), of a rectangular cross section, the thickness of which being up to 40 µm in order to avoid any influence of changing resistance as the frequency is changing. This appears in figure 3. The direction of the multi phase flow through the pipe is shown by F.

Each coil (12 or 14 in figure 1) can be regarded as a parallel coupling between an inductance, a capacitance and a resistance. The capacitance consists of different spread capacitances between the coil windings and an equivalent parallel resistance made up by the resistance in the coil windings and the power loss in the volume of the mixture flowing through the coil. The first one is constant but the second one is dependent on the amount of water in the mixture. The coil is part of a feedback circuit witch latch the excitation frequency to the coil's resonance frequency. The current in the feedback loop will then be dependent on the induced power loss in the mixture. The resonance frequency can be determined by the number of windings in the coil and the optimal frequency range will be dependent on the current penetration depth and the induced power loss in the multi phase flow mixture. The higher the frequency

the higher is the loss and thus the higher is the sensitivity of the meter, but the frequency is limited by the current penetration depth of the induced current in both the mixture and the coil windings.

In oil/gas continuous mixtures the water consists as insulated droplets in the oil/gas. The induced loss in these distributed droplets is small compared to the loss in water continuous mixtures (this is the reason for making the power transformer cores of thin insulated steel plates). However, the penetration depth of the eddy currents is large so we can use higher resonance frequency and thus increase the sensitivity.

Due to this fact two coils are used in the meter according to the invention, and they are simultaneously optimised for oil/gas continuous mixtures and water continuous mixtures respectively.

The induced loss will be dependent on the conductivity in the water component. By using two different coils with different resonance frequencies it is possible to compensate for variation in the conductivity and hence the conductivity of the water can be determined as well.

To keep the coil resistance constant it is important to avoid the frequency dependent resistance in the coil windings due to the electrical penetration depth. This can be avoided by winding the coil with a cable of separately insulated Cu-lices with a radius less than the electrical skin depth of Cu. In our experiment we have used flat Cu-cords at a thickness of 40 µm.

THEORY

The eddy current loss in an infinitely large plate with thickness d (meter) and electrical conductivity σ (Siemens/meter), penetrated by a magnetic field B (Tesla) parallel the plate at a frequency ω (radians/second), is:

(1) $$P_0 = \frac{\sigma\omega^2 d^2 B^2}{12}$$

where B is the rms-value of the penetrating magnetic field, σ the conductivity of the medium and ω the frequency of the magnetic field. The resonance frequency for the different coils lays in the region of 2 to 8 MHz and the electrical conductivity in processed water from the North Sea oil is 4-6 S/m.

The skin depth for the electrical current induced in a conducting medium is:

$$\delta = \sqrt{\frac{2}{\mu_0 \mu_r \omega\sigma}}$$
(2)

where μ_0 and μ_r are the magnetic permeability for the empty space and the relative permeability respectively.

At a frequency of 5.5 MHz which is used for the most sensitive coil for water continuous mixtures the penetration depth for the eddy currents will approximately be 10 cm. This is acceptable for production pipes up to a diameter of 20 cm (8"). The frequency may prefreably be in the range of 1-10 MHz, and most preferably in the range of 2 to 8 MHz.

The skin depth in Tm of the Cu lead in the coil as a function of frequency (Mhz) is shown in the following Figure 2. The figure shows that the thickness of the Cu-lead preferable preferably is up to 40µm.

The coil design of the instruments used in the experiments are as follows:

Fig.3. Nine layer 9 windings of flat Cu-cord (15 x 0.04 mm). f = 5.5 MHZ

Fig.4. One layer, 15 windings of flat Cu-cord, f = 2 MHz

Fig.5. 4 layers, 4 winding coil of flat Cu-cord. f = 9 kHz.

EXPERIMENTAL RESULTS

Fig.3. shows the meter result from a 9-turn coil which is sensitive for the water content in the mixture over the whole range. The impedance kΩ is shown as a function of the water fraction β. The diagram shows that with this meter coil structure the whole range may be determined by the use of one coil only. A change in water content will effect a determinable (or visible) change in the impedance over the whole range.

Fig.4. shows a coil which has an increased sensitivity for oil/gas continuous mixtures. Thus, in the oil/gas continous range, there is marked reduction in impedance as the water fraction increases and a change of water content in the fluid mixture is possible to measure in this range. But it is almost impossible to measure a change in water fraction exeeding about 0,275, as the impedance remains constant wihin said range.

Fig.5. gives the result from the application of a coil configuration that has an increased sensitivity for water continuous mixtures. Thus, in the water continous range, there is marked reduction in impedance as the water fraction increases, and therefore a change of water content in the fluid mixture is possible to measure in this range. But it is almost impossible to measure a change in water fraction up to about 0,2 as the impedance does not change much within this range.

By combining those two last coils used in example 4 and 5, in a meter according to the invention, an increased sensitivity can be obtained both in water discontinuous mixtures and water continuous mixtures.

THE PRINCIPLE USED IN PROCESS TOMOGRAPHY

When the different phases in the crude are separated, i.e. not homogeneous mixed, the water content can not be

measured with the same accuracy as for homogeneous mixtures if the principle explained above is used.

The arrangement for utilising this induction principle in a tomographic arrangement is shown in Fig.6.

Fig.6. is a proposed coil arrangement for tomographic detection of multiphase flow. The figure shows a pipe section 20 of the same material as illustrated in figure 1. To the outside surface of the pipe 20, a number of 8 coil units 22 are mounted in close contacting the pipe surface 24. The three phases gas 26, oil 28 and water 30 are shown inside the pipe section. The water amount may now be measured by means of the arrangement according to figure 6.

A more detailed drawing of one of the coils 22 is shown in figure 7.

Here we can determine the power loss generated in the alternating magnetic field from one coil at the time. Based on mathematical models of the magnetic field from the coils it is possible to work out a reconstruction algorithm imaging the water distribution in the meter cross section. It may also be possible to excite one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration which must be areas of water.

In the new solution, a different electronics is used. Here a resonance circuit is used wherein the resonance frequency is changing as a function of changes in water content and salinity. Also the impedance at resonance changes due to these amendments. By using a resonance circuit the frequency is always locked at resonance frequency, wherein the sensitivity for changes is greatest. Thus one saves one coil so that the new solution is cheaper and simpler.

In an oil-water mixture the flow may be divided in oil-continous flows at low water fractions and water-continous flows at low oil fractions. As can be seen from the plot, where the impedance is plotted as a function of

the water fraction, the curve exhibits a discontinuity. At this point, the flow shanges from oil-continous to water-continous or vice versa. See figures 3, 4 and 5.

Measurements have shown that the sensitivity in the two areas depends on the number of windings and whether the coil is wound with standard copper wire or copper tape.

This provides for excellent flexibility where the sensitivity may be optimized for a given application. For example if one wishes to obtain a maximum sensitivity for low water fractions in oil. In another application one may wish a maximum sensitivity for low oil fractions in water. This requires two different coils according to the invention, and if two coils according to figure 1 are combined, a maximum sensitivity over the whole of the meassuring area (see figures 4 and 5) is obtained. A possibility to compensate for changes in salinity is another advantage which may be obtained.

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[3] Ragnvald Soldal, *Detection of Water Cut and Levels in Separator Using High Frequency Magnetic Field* (In Norwegian), Cand. Scient Thesis, University of Bergen, 1999.

[5] A J Peyton, M S Beck, A R Borges, J E de Oliveira, G M Lyon, Z Z Yu, M W Brown, J Ferrerra, *Development of Electromagnetic Tomography (EMT) for Industrial Applications. Part 1: Sensor Design and Instrumentation.*

Proceeding of 1st World Congress on Industrial Process Tomography, Buxton, Greater Manchester, April 14-17, 1999, 306.

PATENT CLAIMS

1. Method for determining the content of a conductive component of a multi phase flow, in a fluid transporting body such as a pipe, characterized in on line measuring the fraction of the conductive component in the multi phase flow by using a coil design optimised for non-conductive continous mixtures, and a coil optimised for conductive continous mixtures mixtures.

2. Method according to claim 1, characterized in measuring the induced loss which is dependent on the the conductivity of the conducive phase component.

3. Method according to claim 1-2, characterized in the two coils operating at two different frequencies in order to compensate for variation in the conductivity, hence determining said conductivity of the conductive phase.

4. Method according to claim 1-3, characterized in using a coil winding which arranged of a cable of separately insulated conductive wire or cords.

5. Method according to claim 1-4, characterized in using wire or cords includes Cu-lices having a radius less than the electrical skin depth of Cu (copper).

6. Method according to any of preceding claims, characterized in using flat Cu-cords at a thickness of 40 Tm.

7. Method according to any of preceding claims, characterized in using a resonance frequency in the range of 1-10, and preferably in the range of 2 to 8 MHz.

8. Method according to any of preceding claims, characterized in using a resonance frequensy of 5,5 Mhz in order to obtaining a penetration depth of about 10 cm.

9. Method according to any of preceding claims, characterized in using a multi turn coil, e.g. a 9-turn coil, which is sensitive for conductive liquid content (such as water) in the mixture over the whole range.

10. Method according to any of preceding claims, characterized in using a number of coils arranged to the outside surface of the fluid transporting body, such as pipe, the coils being arranged to be driven to reconance frequency.

11. Method according to any of preceding claims, characterized in determining the power loss generated in the alternating magnetic field from one coil at the time.

12. Method according to any of preceding claims, characterized in working out a reconstruction algorithm imaging the water distribution in the meter cross section based on mathematical models of the magnetic field from the coils.

13. Method according to any of preceding claims, characterized in exciting one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration being areas of water.

14. Arrangement of determining water content in multi phase flows in a fluid transporting body, characterized by a coil design optimised for non-conductive continous mixtures, and a coil optimised for conductive continous mixtures mixtures.

15. Arrangement according to claim 14, characterized by a number of coils arranged to the outside surface of the

fluid transporting body (such as a pipe), the coils being arranged to be driven to reconance frequency.

16. Arrangement according to claim 14, characterized by a multi turn coil, e.g. a 9-turn coil, which is sensitive for water content in the mixture over the whole range.

17. Arrangement according to any of preceding claims, characterized by a number of coils arranged to the outside surface of the fluid transporting body, such as pipe, the coils being arranged to be driven to reconance frequency.

18. Arrangement according to any of preceding claims, characterized in determining the power loss generated in the alternating magnetic field from one coil at the time.

19. Arrangement according to any of preceding claims, characterized by a reconstruction algorithm imaging the water distribution in the meter cross section based on mathematical models of the magnetic field from the coils.

20. Arrangement according to any of preceding claims, characterized in being enabled to exciting one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration being areas of water.

21. Application of the method and arrangement according to preceding claims, for determining the water content of a multi phase flow of oil, hydrocarbon gas and water, in that water is the conductive component to be determined and the oil and gas phases being the non-conductive phase.

22. Application of the method and arrangement according to claims 10-13, for measuring water content in oil/gas/water multiphase mixture flows wherein the different phases in the crude are separated, i.e. not homogeneous mixed.

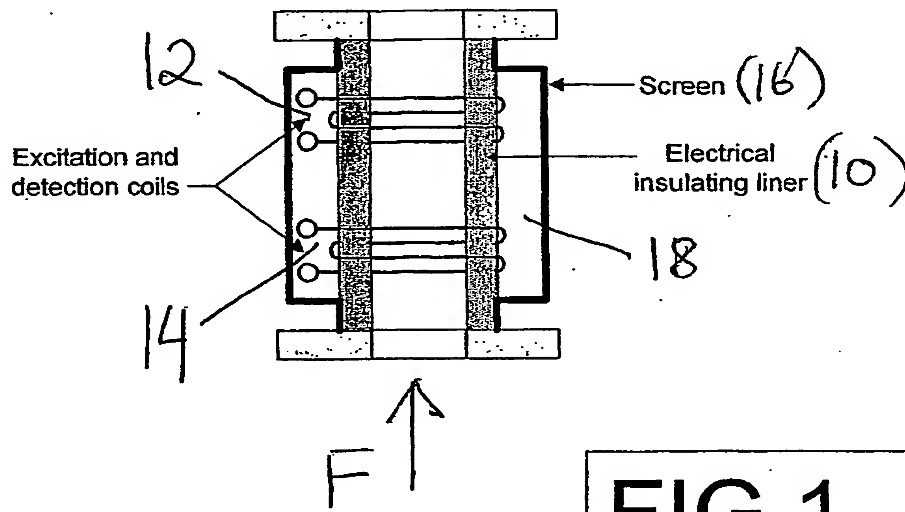
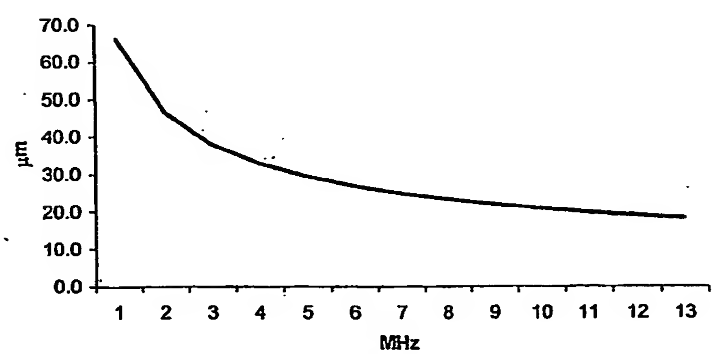

12
Screen (16)
Excitation and
detection coils
Electrical
insulating liner (10)
18
14
F

FIG 1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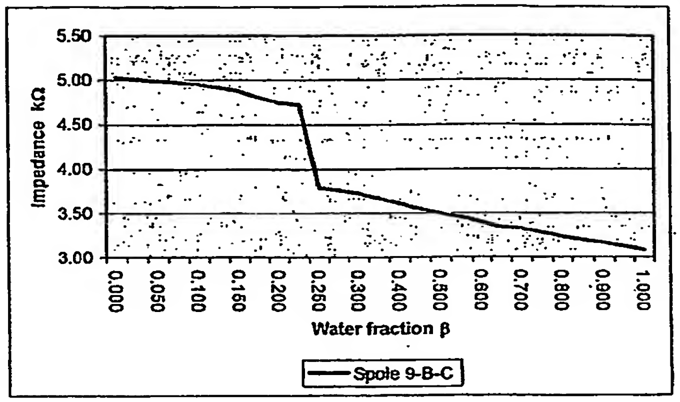
11
12
13
MHz

FIG 2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0.250
0.300
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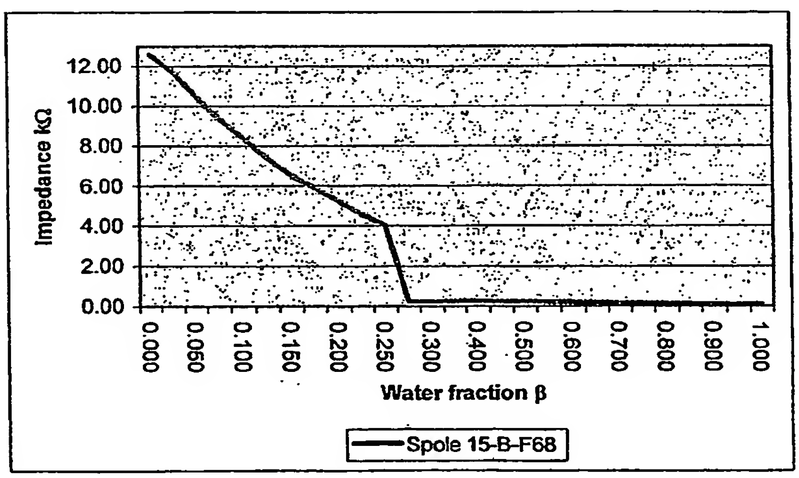
0.500
0.600
0.700
0.800
0.900
1.000
Water fraction β
Spole 9-B-C

FIG 3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0.150
0.200
0.250
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Water fraction β
Spole 15-B-F68

FIG 4

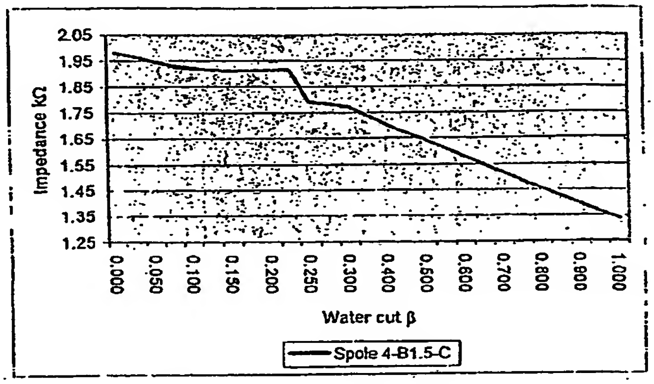

FIG 5

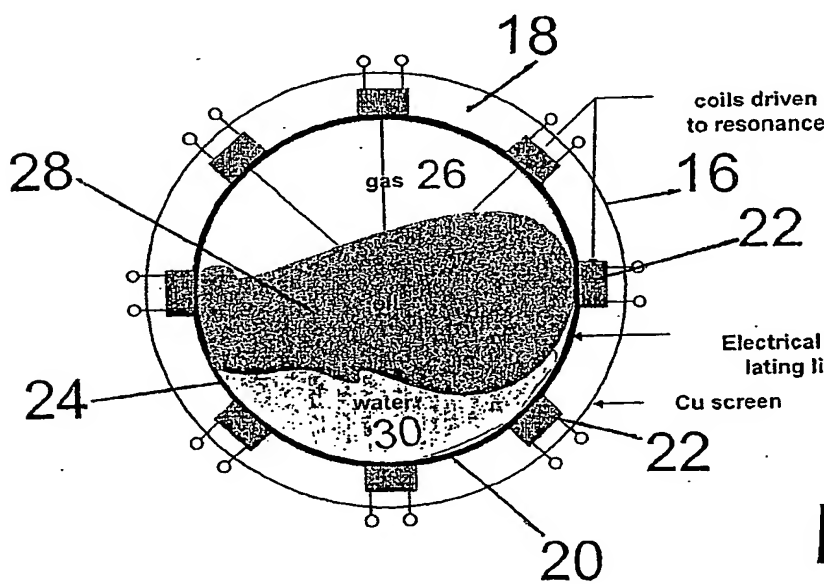

FIG 6

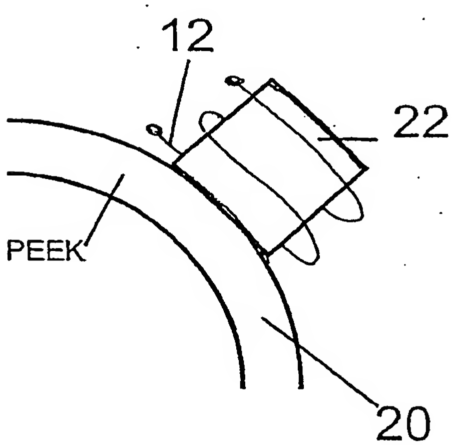

FIG 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00313

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01N 27/00, G01N 33/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01N, G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL,WPI,PAJ,INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,Y	WO 0052453 A2 (STEAG MICROTECH GMBH), 8 Sept 2000 (08.09.00), page 5, line 20 - page 6, line 28, figure 1, claim 1, abstract --	1-22(IN PART)
Y	US 4458524 A (R.MEADOR ET AL), 10 July 1984 (10.07.84), column 3, line 35 - line 60, figure 5, abstract --	1-22(IN PART)
Y	US 5389883 A (R.HARPER), 14 February 1995 (14.02.95), column 2, line 22 - column 3, line 19, figures 1,5, abstract --	1-22(IN PART)

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 November 2003	28 -11- 2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Gordana Ninkovic´ / itw Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00313

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 1-22 (in part)
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see extra sheet

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box I

Present claims relate to a method and an arrangement for measuring conductive component content of a multiphase fluid flow and uses thereof. However claims 1-22 lack of essential features (Art 6 PCT; Rule 6.3 PCT) to such an extent that a meaningful search over the whole claimed range is impossible (Art 17 (2) PCT).
The claims are merely statements of desiderata, defined by reference to desirable properties, namely "using coil design optimised for non-conductive continuous mixtures and a coil optimised for conductive continuous mixtures". Therefore a novelty search covering the whole claimed scope of claims 1-22 is not possible.
The application provide support within the meaning of Article 6 PCT and disclosure within the meaning of Article 5 PCT only for a device with two coils arranged around the pipe comprising the fluid to be measured, where the induced power loss in the mixture is determined, alternatively a number of coils arranged on the outside surface of the fluid transporting pipe. Consequently, the search preformed is only considered to cover the embodiments described in the application.

The applicant's attention is drawn to the fact that claims relating to the invention in respect of which no international search report has been established will not be the subject of an international preliminary examination (Rule 66.1(e) PCT). This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

06/09/03

International application No.
PCT/NO 03/00313

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0052453 A2	08/09/00	DE 10009402 A	03/05/01
US 4458524 A	10/07/84	NONE	
US 5389883 A	14/02/95	GB 2271637 A,B	20/04/94
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